

Concepts of Vector-Sum Control for CW-operation

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DESY

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Outline

- Principle of vector sum control
- High Q_1 cavities and microphonics
- Simulation results
- Calibration errors
- Summary

General Definitions

cavity differential equation

$$\begin{bmatrix} \dot{V}_I \\ \dot{V}_Q \end{bmatrix} = \begin{bmatrix} -\omega_{1/2} & -\Delta\omega(t) \\ \Delta\omega(t) & -\omega_{1/2} \end{bmatrix} \cdot \begin{bmatrix} V_I \\ V_Q \end{bmatrix} + R \cdot \omega_{1/2} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} I_I \\ I_Q \end{bmatrix}$$

$$f_{rf} = 1.3 \cdot 10^9 \text{ Hz}$$

$$Q_l = 3 \cdot 10^7$$

$$\left(\frac{r}{Q}\right) = 1024 \frac{\Omega}{m}$$

$$\omega_{rf} = 2 \cdot \pi \cdot f_{rf}$$

$$\Delta\omega = \omega_{rf} - \omega_0$$

$$\omega_{1/2} = \frac{\omega_{rf}}{2 \cdot Q_l} \quad R = \left(\frac{r}{Q}\right) \cdot Q_l$$

$$\omega_{1/2} \approx 136 \frac{1}{s}$$

Vector sum (VS)

$$V_{VS} = \frac{1}{N} \sum_{i=1}^N V_i + \Delta V$$

$N \rightarrow$ number of cavities

$\Delta V \rightarrow$ gradient deviation

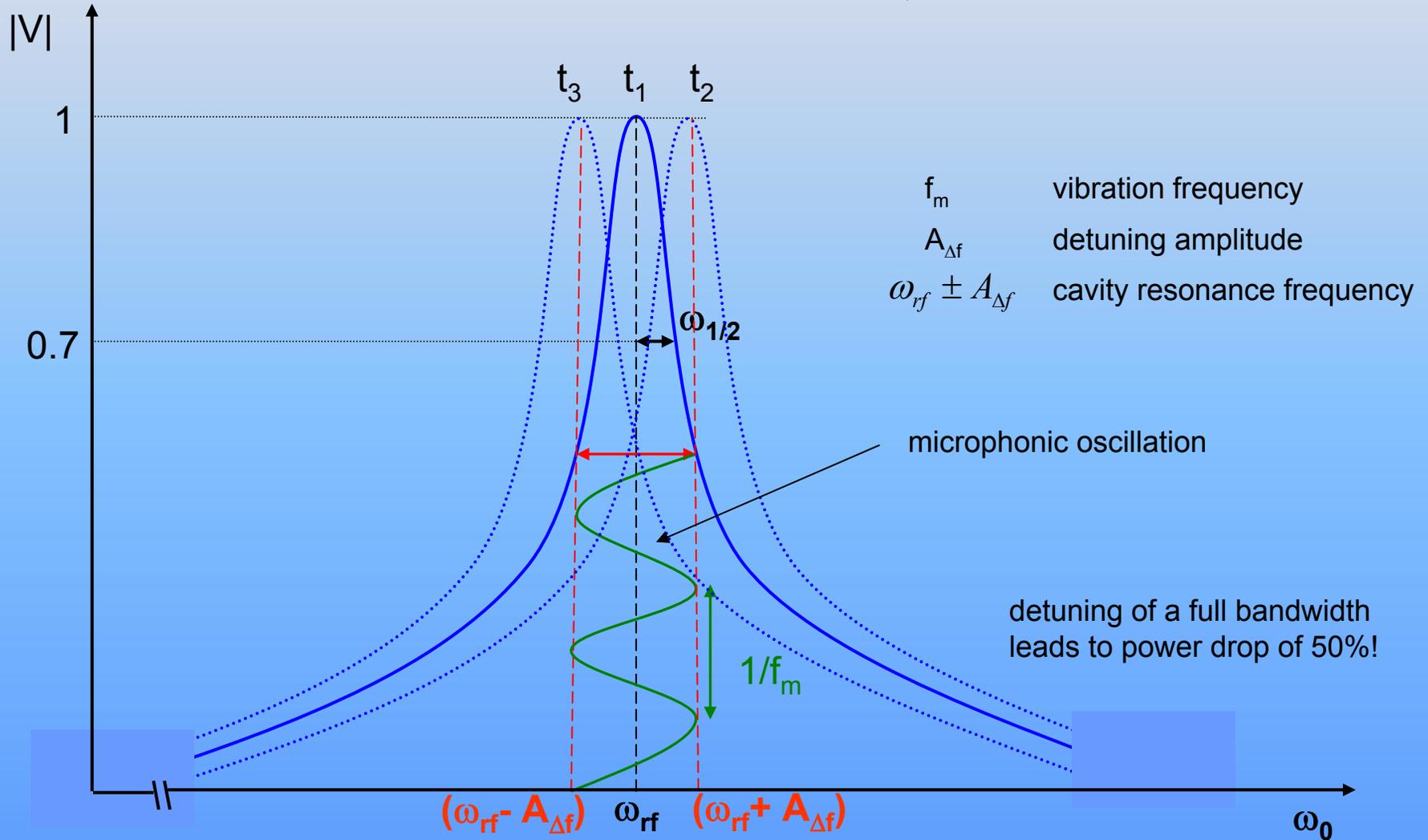
$V_i \rightarrow$ individual cavity gradient

deviation in the individual cavity fields are caused by detuning effects like microphonics.

Cavity Resonance Curve

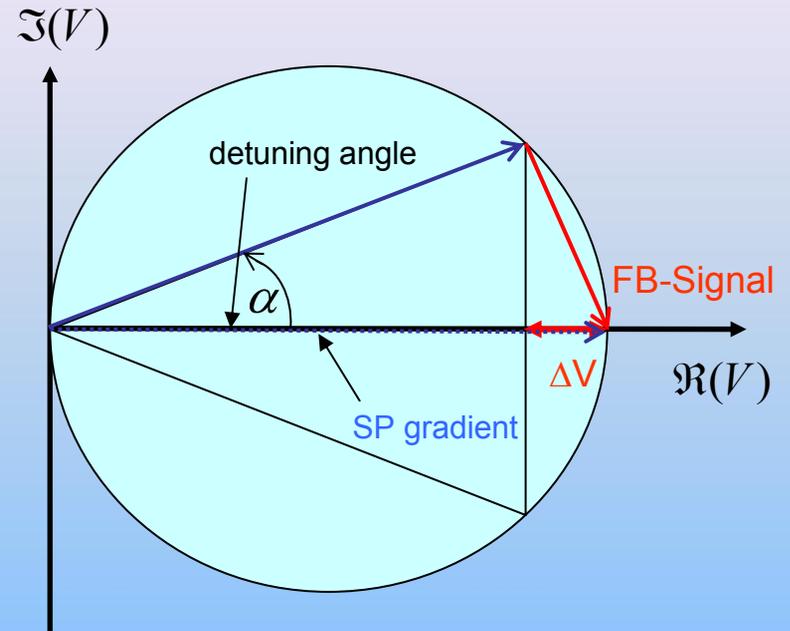
resonance frequency of the cavity changes because of microphonic oscillations during time.

$$\Delta\omega(t) = A_{\Delta f} \cdot \sin(2\pi \cdot f_m \cdot t + \varphi)$$

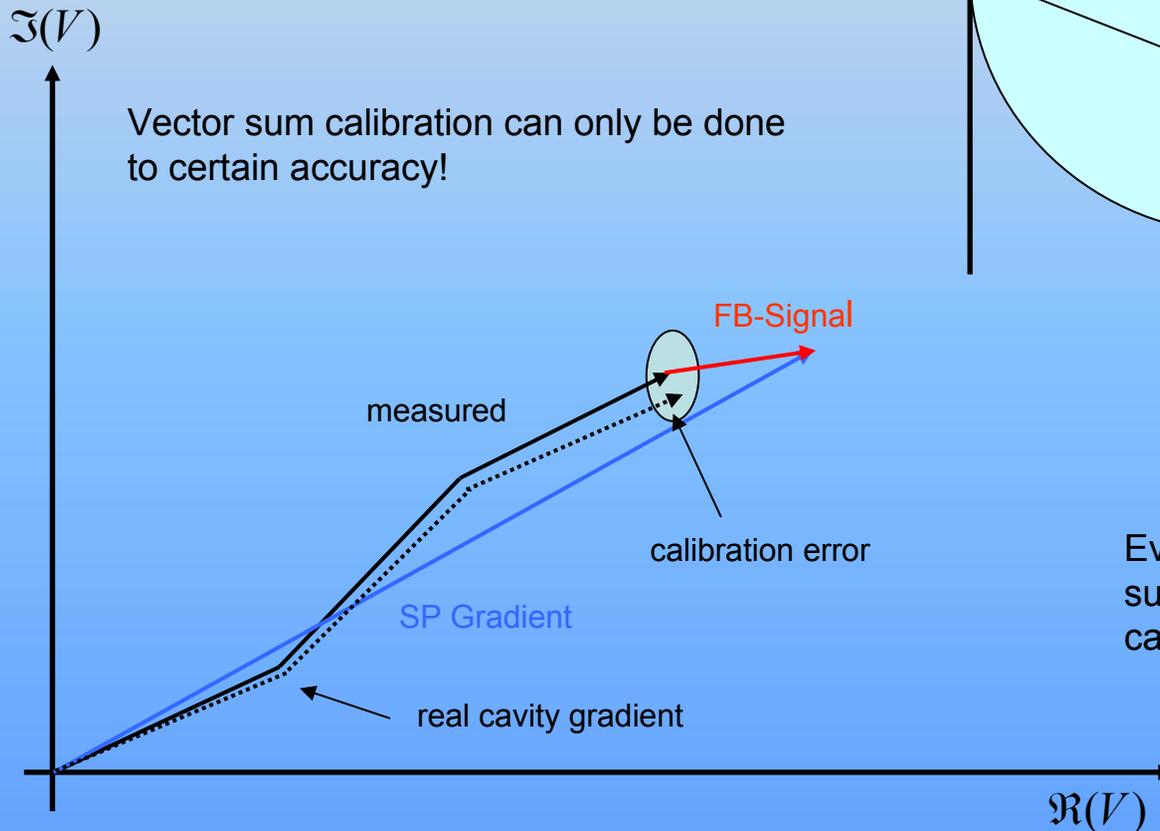


Vector Sum of N Cavities

In presence of microphonic noise the actual field vector as seen by the beam will fluctuate, even if the measured vector is held constant, if the VS errors are non zero.



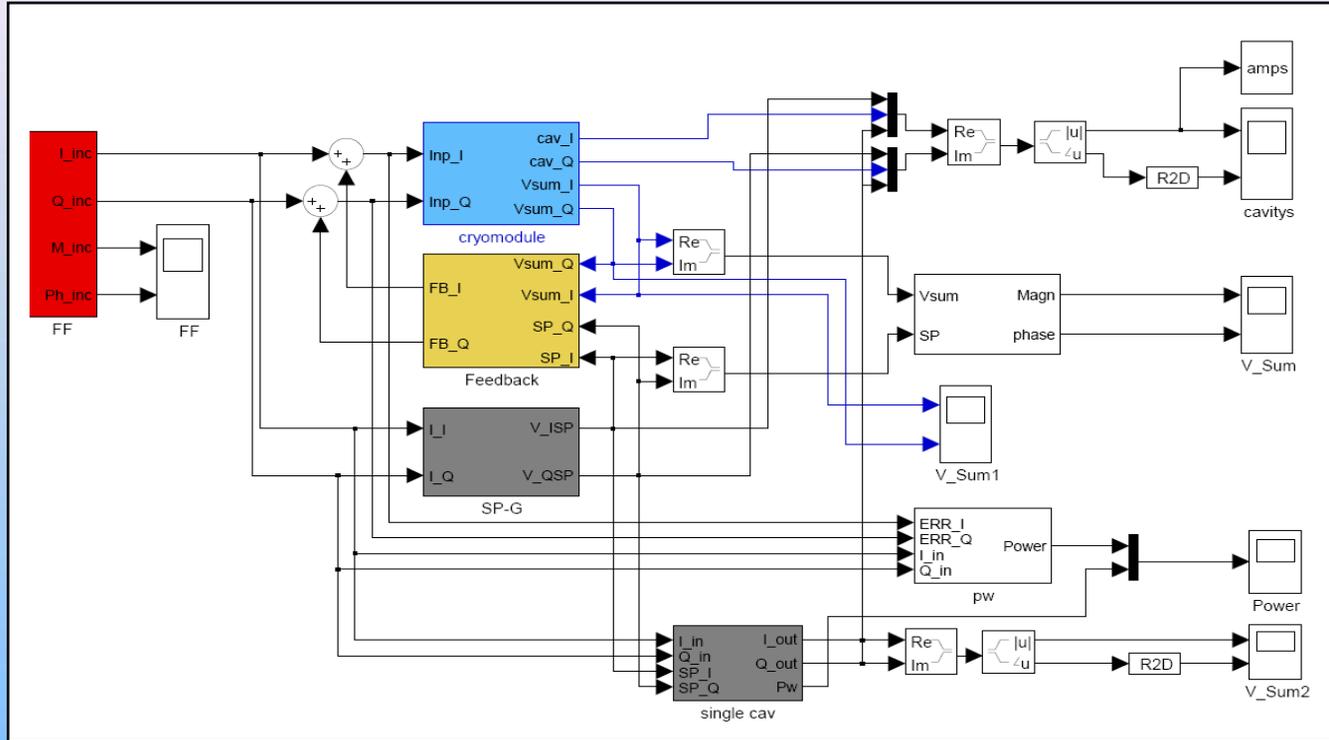
$$\alpha = \arctan \frac{\Re(V)}{\Im(V)}$$



Vector sum calibration can only be done to certain accuracy!

Even with well regulated vector sum, individual cavity gradients can fluctuate.

Simulink Model



model parameters:

$$f_{rf} = 1.3 \cdot 10^9 \text{ Hz} \quad P_{FF} = 3.25 \text{ KW}$$

$$Q_l = 3 \cdot 10^7 \quad f_m = 10 / 100 \text{ Hz}$$

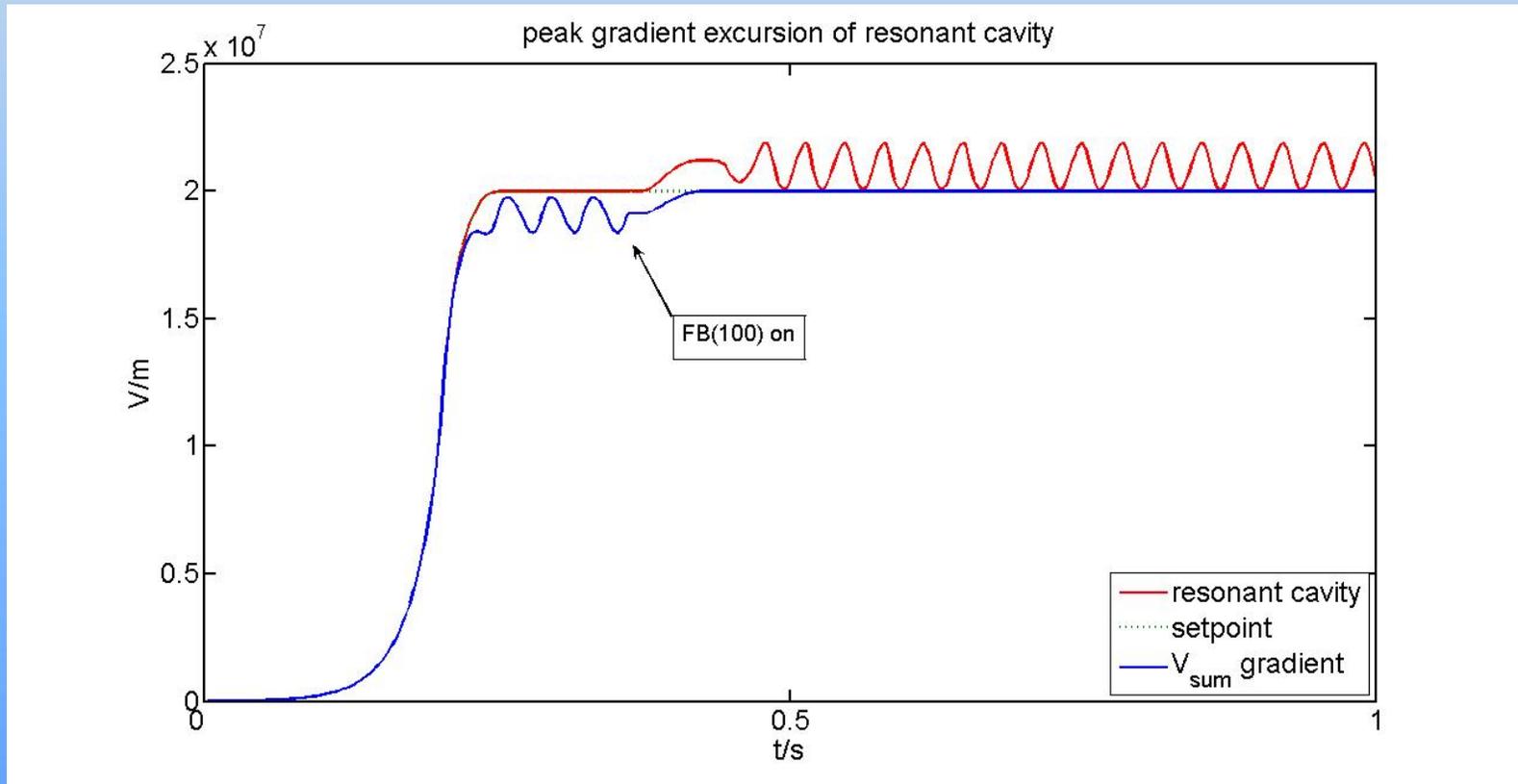
$$K_{FB} = 100 \quad V_{SP} = 20 \text{ MV/m}$$

- variable number of cavities
- decoupled cavities
- no lorentz force detuning

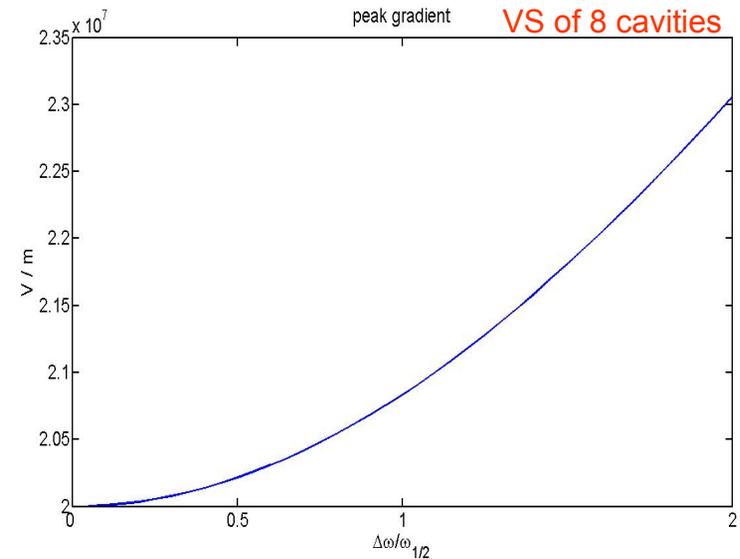
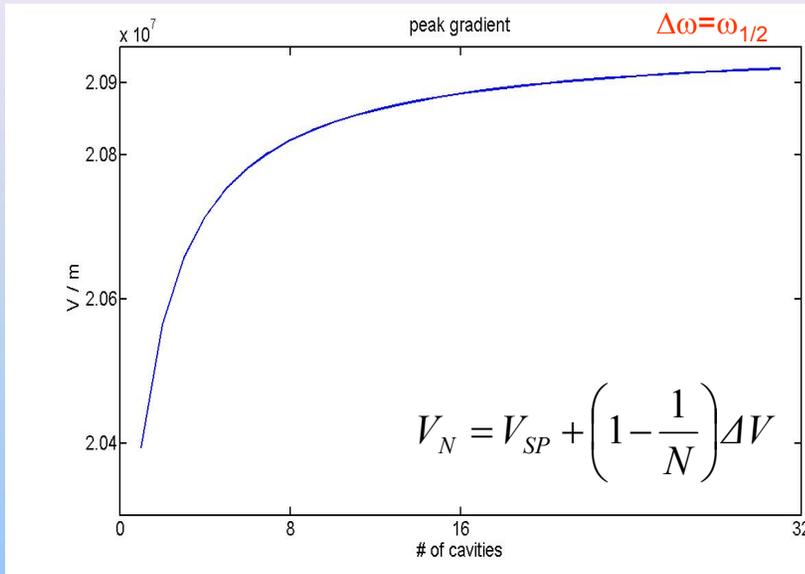
Scenario 1

worst case assumption: (N-1) - cavities oscillate with same microphonic vibration
N - cavity is microphonic-free ($\Delta\omega = 0$)

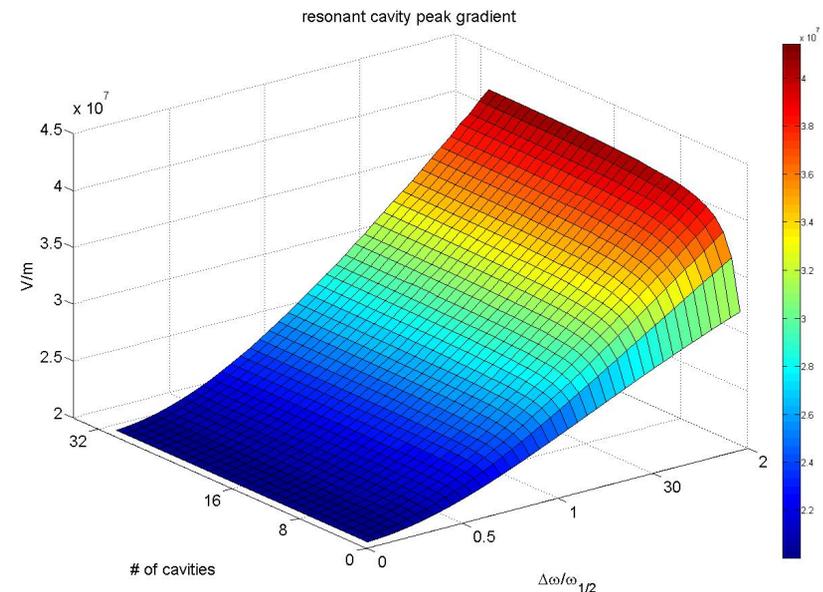
➔ feedback will lead to increase in gradient of cavity N



Max Gradient in Resonant Cavity



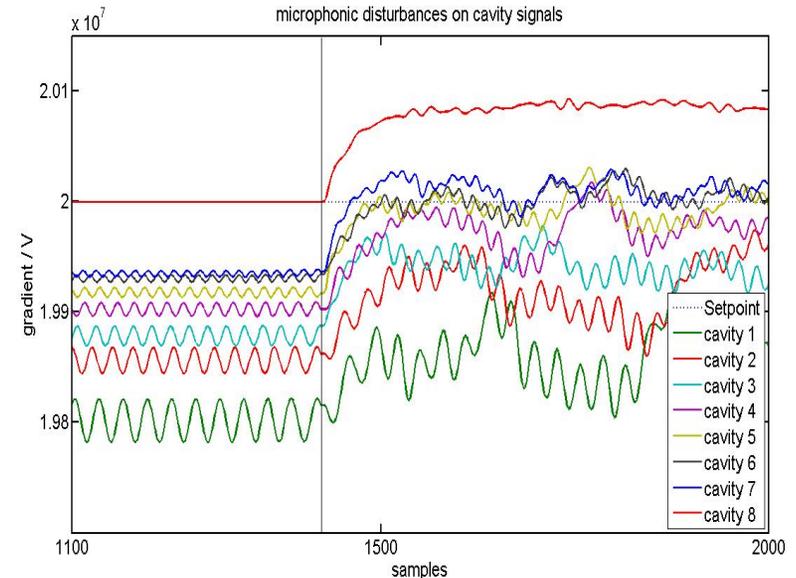
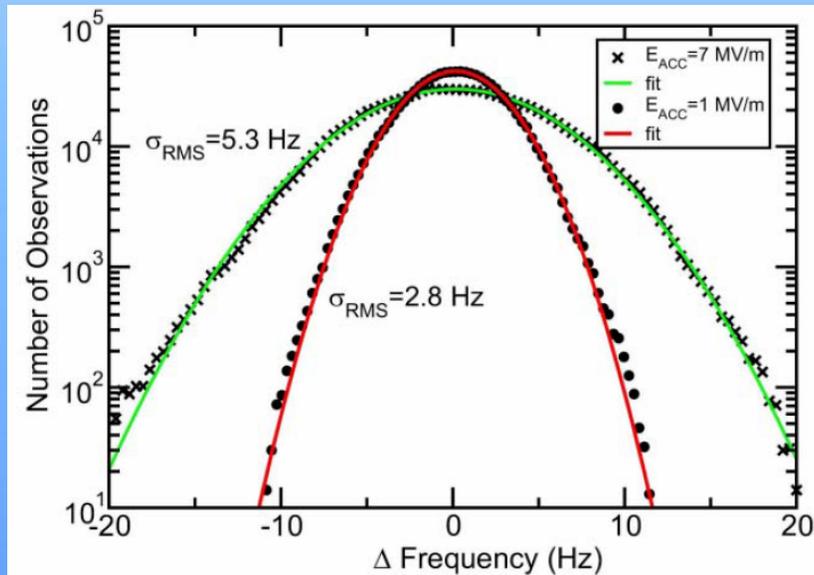
- ➔ increasing # of cavities leads to a limit peak gradient
- ➔ small detuning $\sim V_{\max}^2$
- ➔ for high frequency microphonics ($> \omega_{1/2}$) effect becomes much smaller



Microphonic simulations

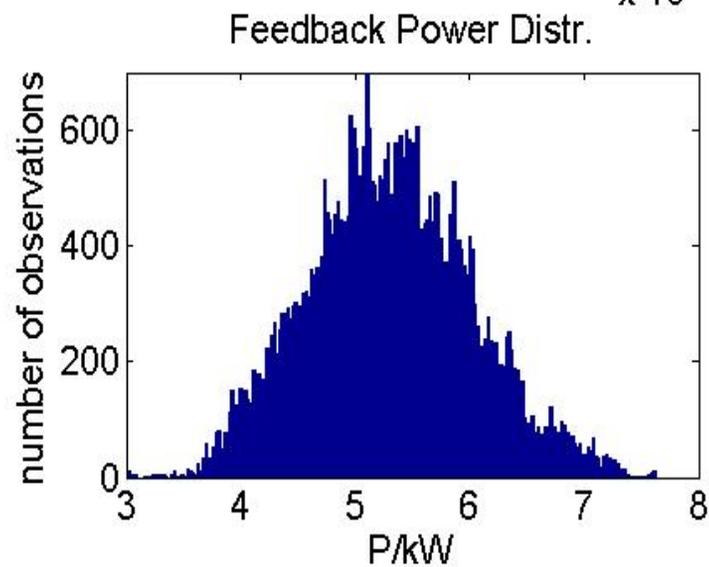
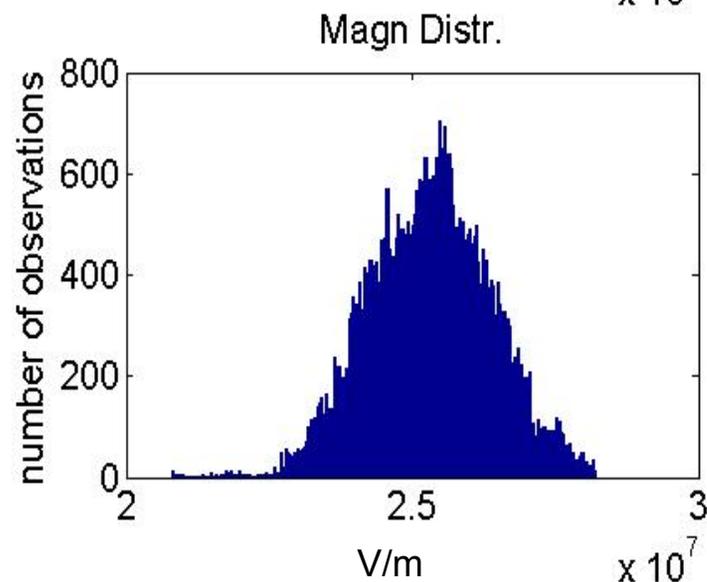
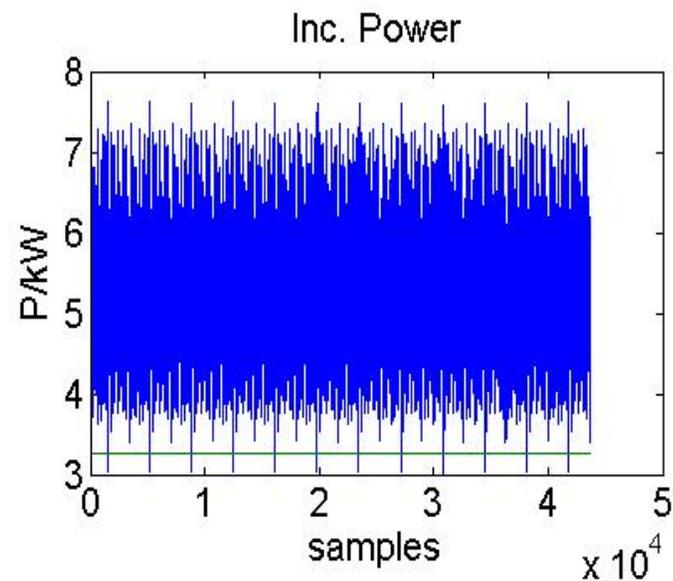
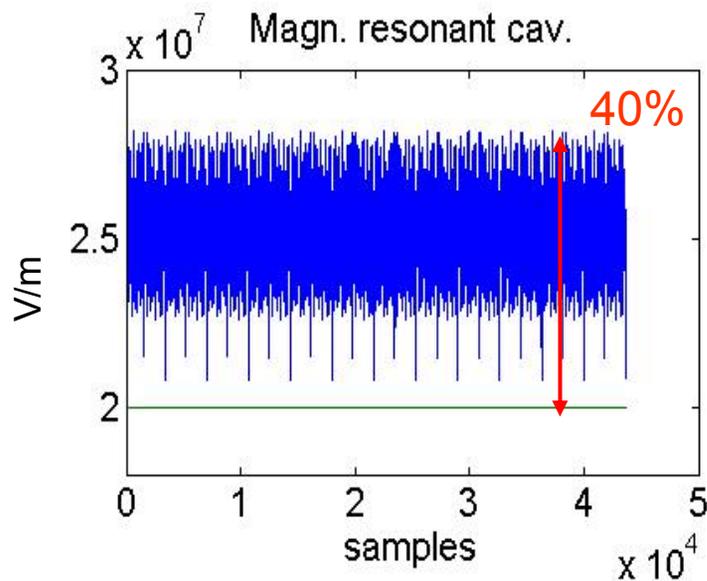
➔ vector sum of 8 cavities, where cav.1-7 have different oscillations and cav. 8 ($\Delta\omega=0$) gives observation data

➔ Assume sinusoidal microphonics. some statistics included with Frequency spread over cavities (10-20 / 100-200 Hz)



➔ Real microphonics have totally different probability distribution. i.e peak gradient excursions will be rare.

$$f_m = 10\text{-}20 \text{ Hz} / A_{\Delta f} = \omega_{1/2}$$



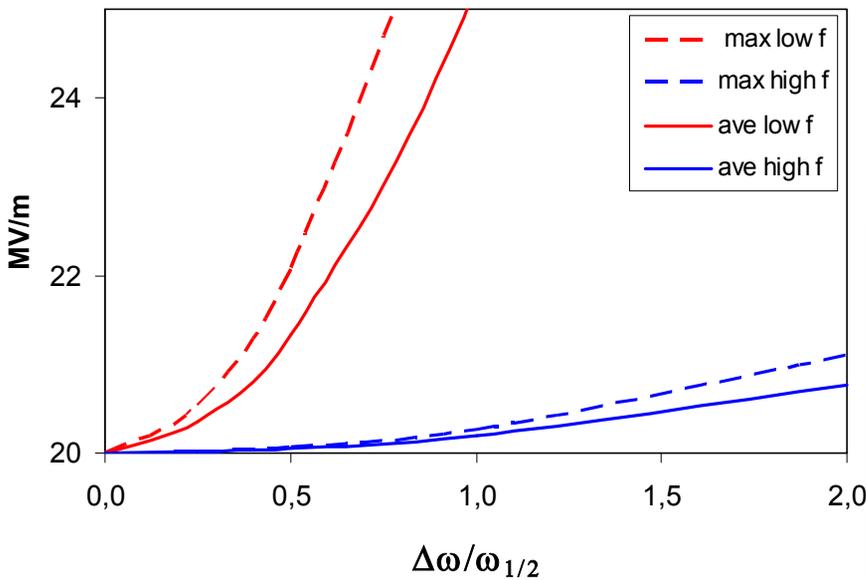
Simulation results

FF →

$$P_{FF} = 3.25 \text{ kW}$$

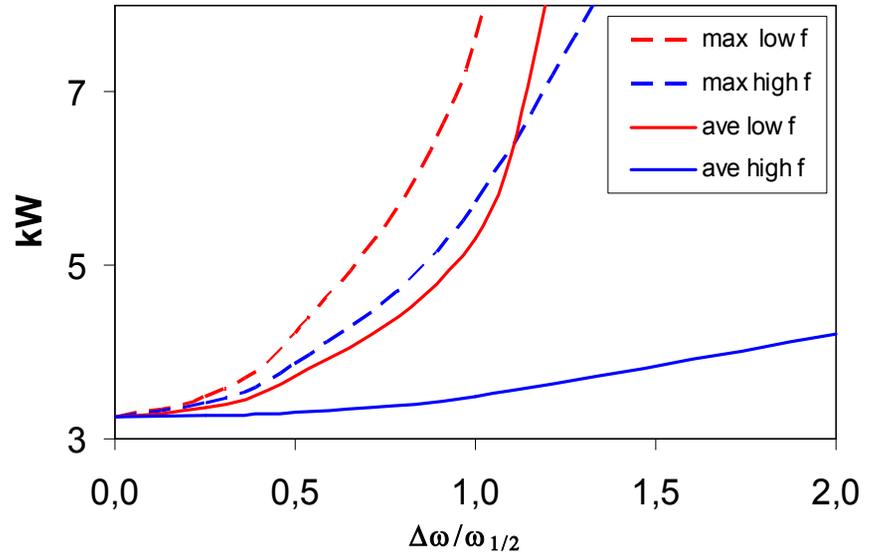
$$V_{SP} = 20 \text{ MV/m}$$

Gradient



V_{ave} MV/m	P_{max} kW	P_{ave} kW
20.36	3.486	3.37
21.34	4.215	3.725

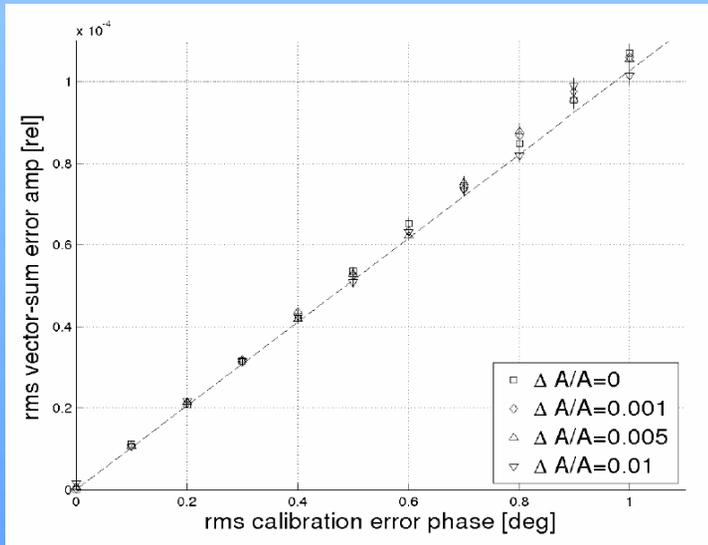
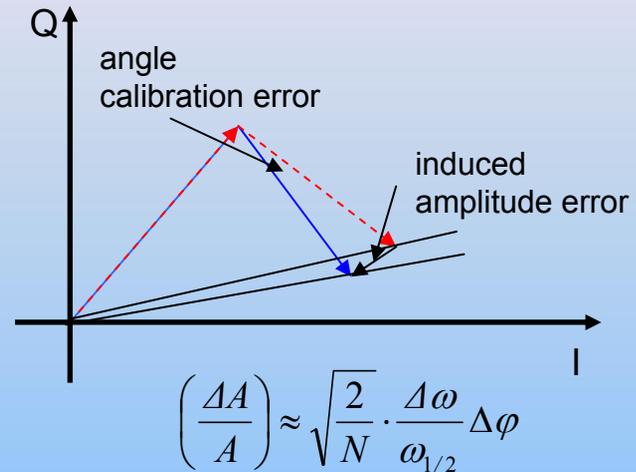
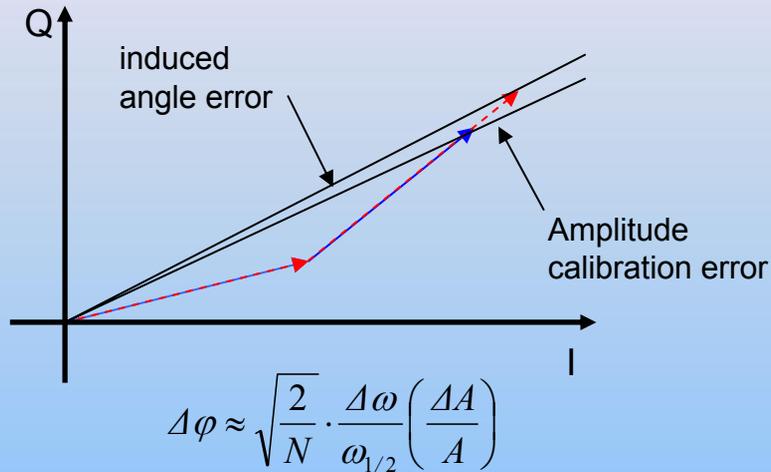
Power



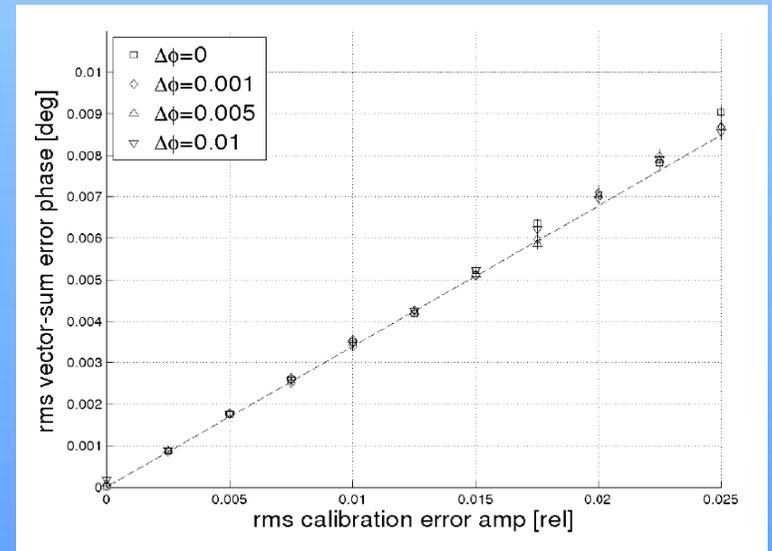
7	100-200	$\omega_{1/2}$	20.2
8	100-200	$2 \omega_{1/2}$	21.1

Calibration Error

Amplitude and phase error



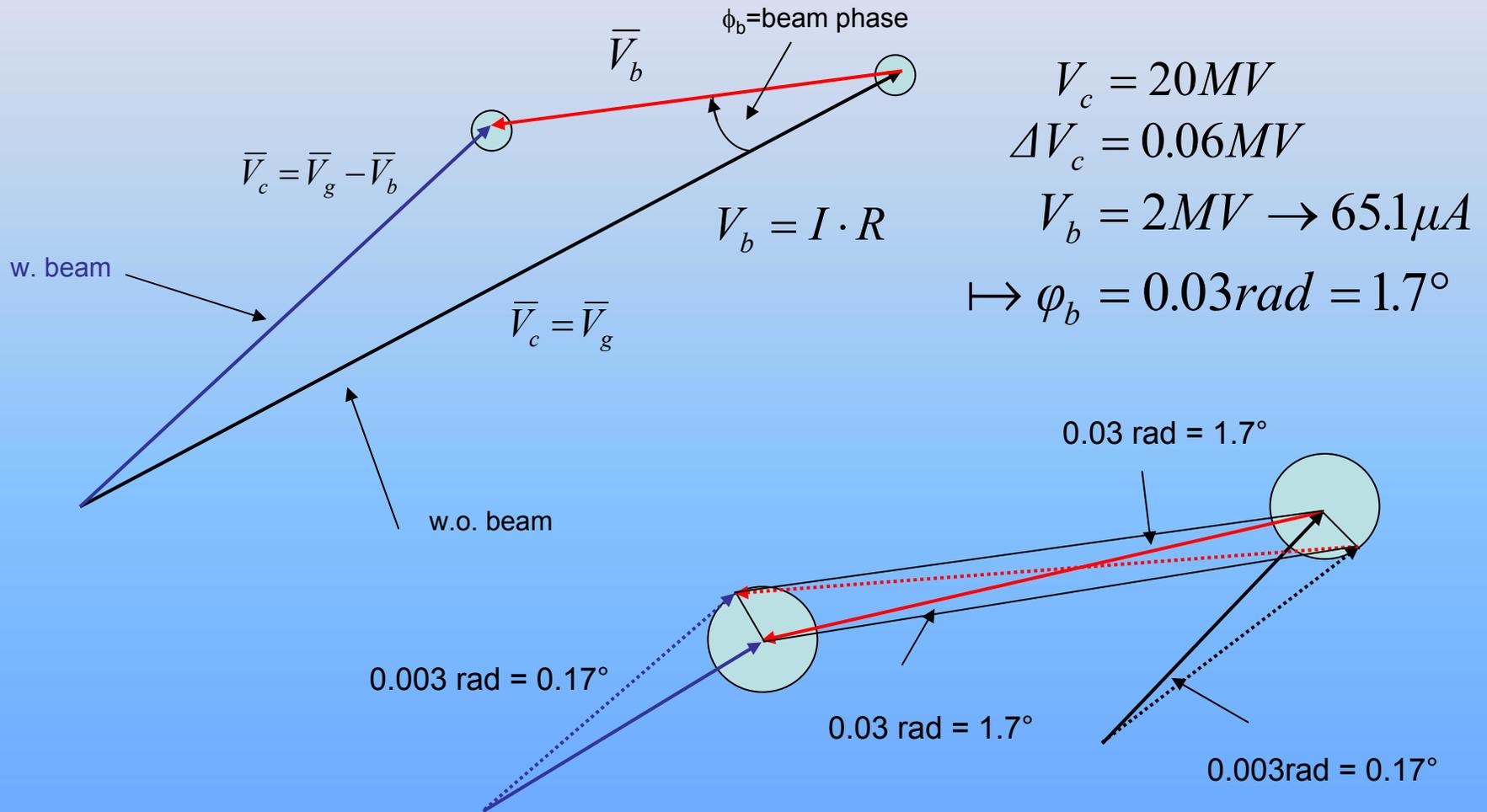
A.Brand



A.Brand

Field Stability and Calibration Error

estimation of the calibration error:

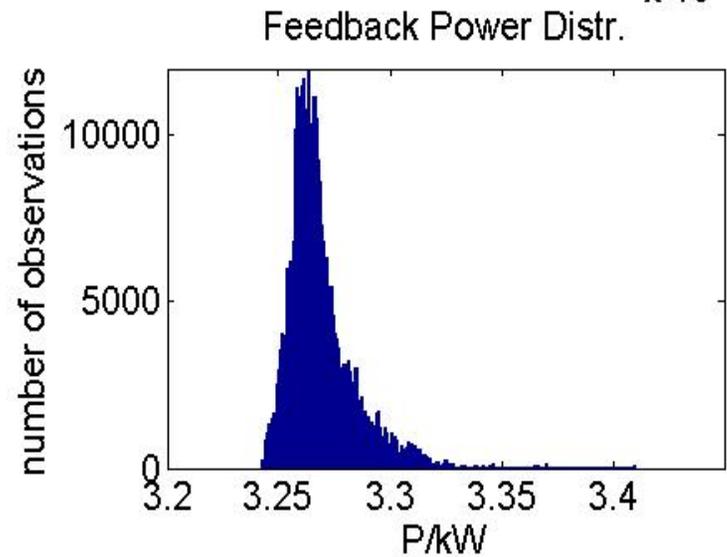
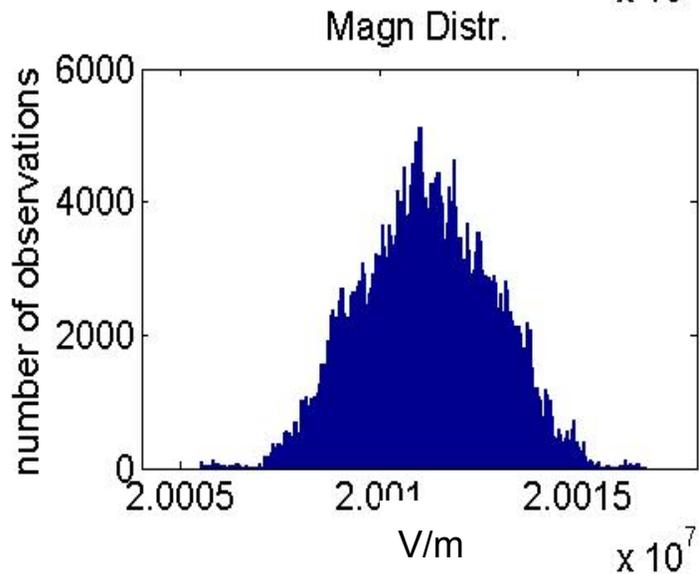
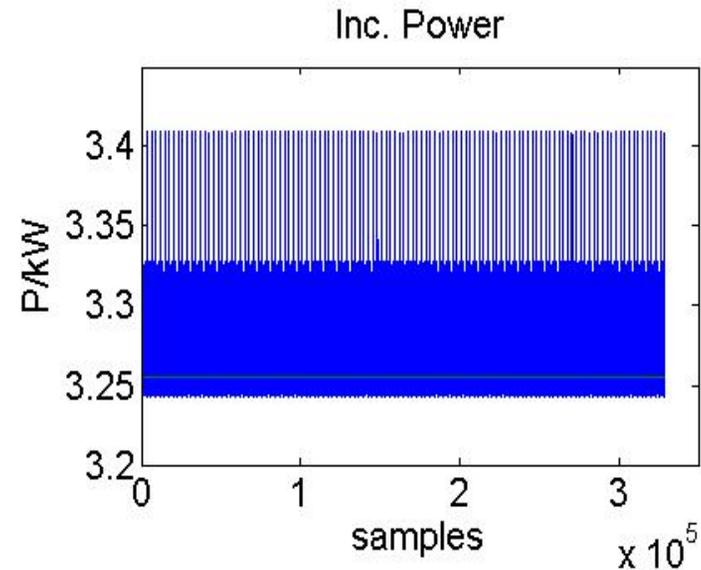
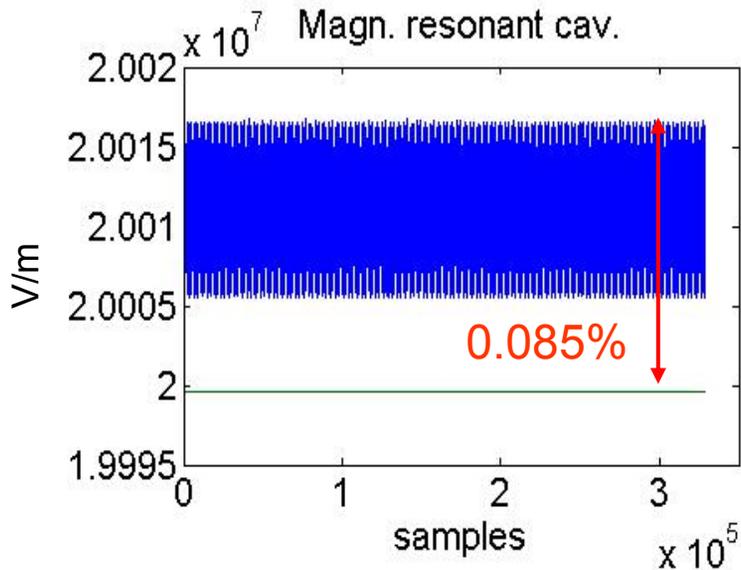


If its possible to measure the field vector with an accuracy of 0.3%, then the vector sum can be calibrated with an accuracy of 3% and 1.7 degrees

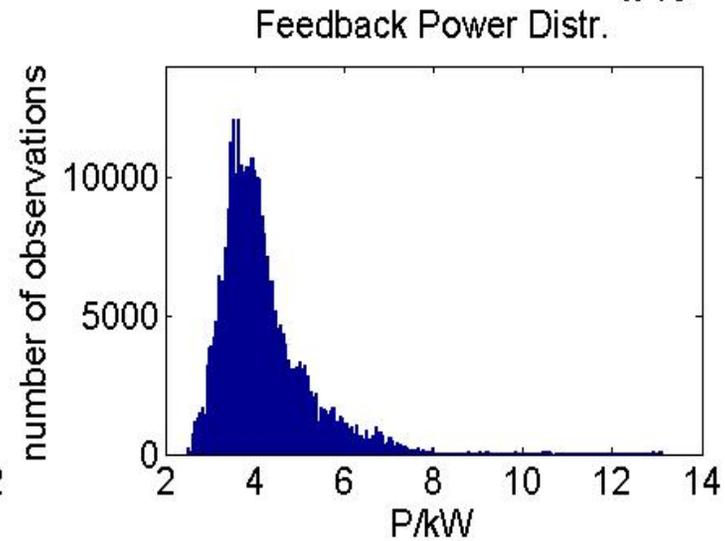
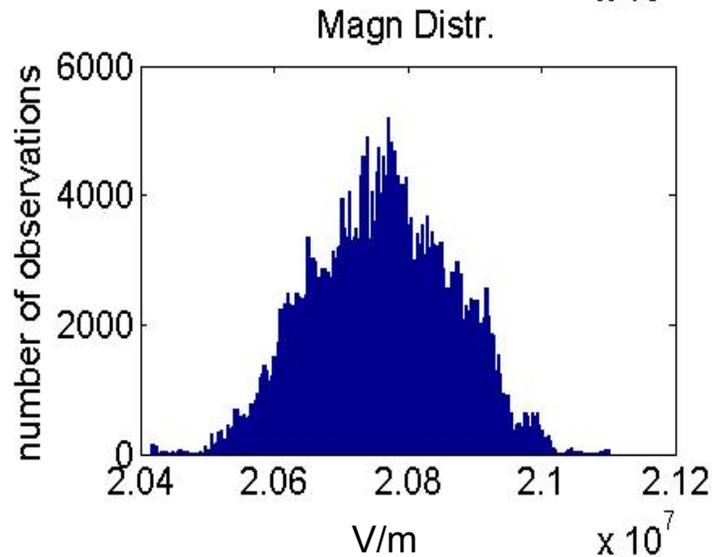
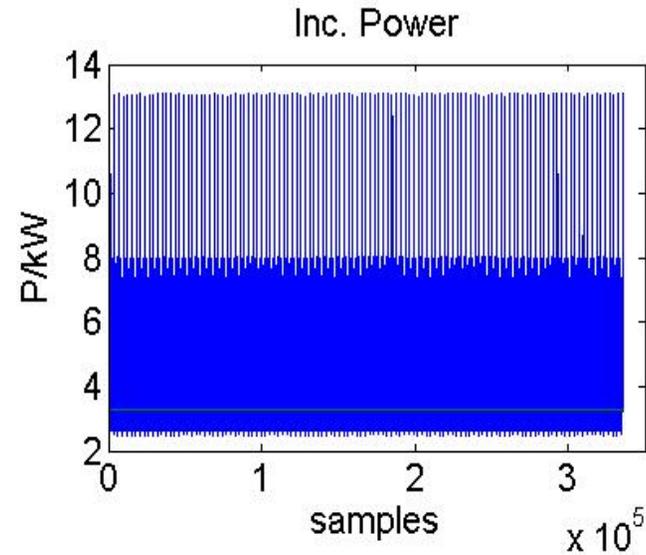
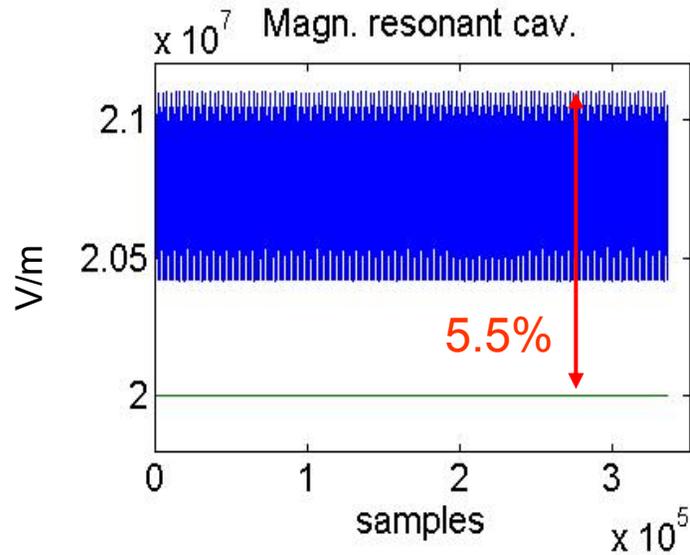
Summary

- Vector sum control should be considered for cw operation of high loaded Q cavities
- The simulations presented demonstrate that microphonic levels of two bandwidths ($f_m > 100$ Hz) or half bandwidths ($f_m < 20$ Hz) can be accepted
- Peak gradient and power excursions will occur very rarely for real microphonic probability distributions. Operational procedures could be developed to allow higher microphonics.
- further studies including vector sum calibration requirements with real microphonics distributions will improve quantitative understanding

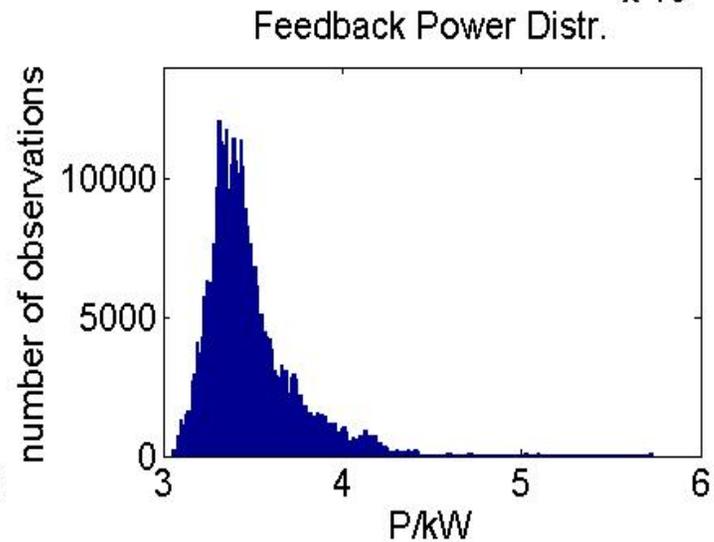
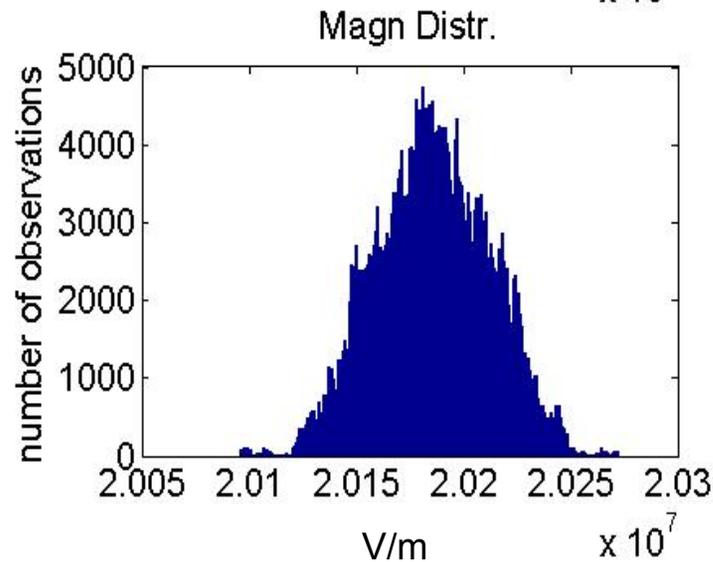
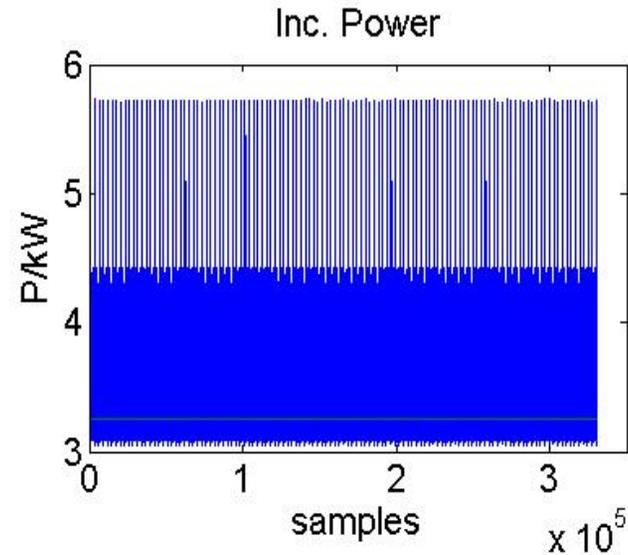
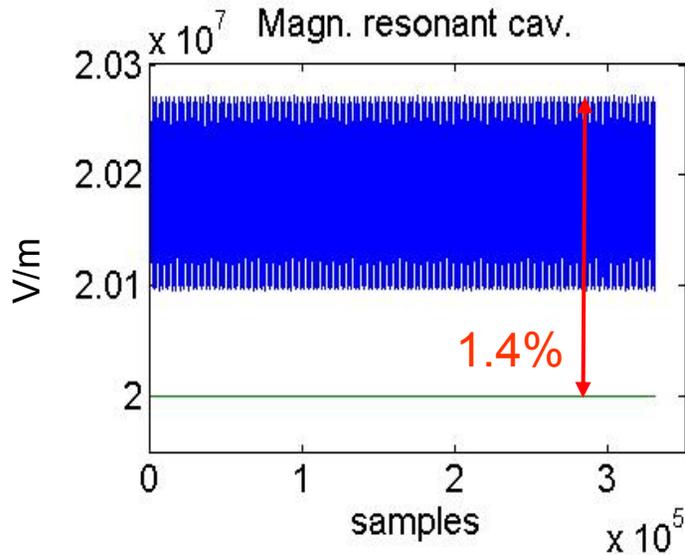
$$f_m = 100-200 \text{ Hz} / A_{\Delta f} = 0.25 \omega_{1/2}$$



$$f_m = 100 - 200 \text{ Hz} / A_{\Delta f} = 2 \omega_{1/2}$$



$$f_m = 100\text{-}200 \text{ Hz} / A_{\Delta f} = \omega_{1/2}$$



$$f_m = 10\text{-}20 \text{ Hz} / A_{\Delta f} = 0.5 \omega_{1/2}$$

